

USING LIFE HISTORY DATA TO COMPARE THE EVOLUTIONARY STRATEGIES OF EUROPEAN URODILES AND ANURANS, AND TO ASSESS THE RELATIONSHIP BETWEEN FECUNDITY AND BODY MASS

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ABSTRACT

In an effort to maintain evolutionary fitness, species utilize life history strategies which often involve tradeoffs. For instance, some species may produce more offspring than others, but these offspring may have a high rate of mortality. Fecundity differences between species may be explained by the pace-of-living syndrome hypothesis, which proposes that larger species typically have lower rates of metabolism and thus live longer lives than smaller organisms. To assess whether there is a relationship between body mass and the number of offspring produced, a scaling analysis was performed on data from 36 European amphibian species. Additionally, the quantity of offspring produced by 2 clades of amphibians with contrasting reproductive strategies (urodeles and anurans) was compared to investigate whether these different life history approaches result in tangible differences in fecundity. This research demonstrated a significant relationship between body mass and offspring produced in amphibians as a whole and the anuran clade, potentially due to the pace-of-living syndrome hypothesis and differences in resource acquisition; interestingly, this finding was not supported by urodele data. Further, anuran species tended to produce more offspring than urodele species of similar masses, possibly supporting the concept of a life history tradeoff. Through analysis of this data, researchers will progress in our understanding of the relationship between intrinsic factors and life history traits, thus furthering the world's understanding of tactics necessary to maintain evolutionary fitness.

Key words: Anurans, Evolutionary Strategies, Life History Traits, Pace-of-Living Syndrome Hypothesis, Urodeles

INTRODUCTION

When attempting to understand how species are able to persist throughout time, ecologists rely on life histories. Crucial to understanding the intricacies of a particular species, a life history is a detailed sequence of events that occur throughout an organism's life (Thompson, 2017). Included in an organism's life history is information like the age of

first reproduction, body mass, fecundity, and mortality rates. By studying a species' life history traits, ecologists can further their understanding of the strategies which they employ to be evolutionarily successful.

Evolutionary fitness is gauged by an organism's ability to survive and reproduce, so in an ideal world, a successful species' life history would be characterized by high rates of reproduction and high

survival rates of offspring and parents. However, this optimum combination is not practical. Instead, species experience tradeoffs, meaning that they may be exceptional in some areas and poor in others. For instance, some species may have a high reproductive rate, but low survival rate. In contrast, other species may have very low reproductive rates but high survival rates to compensate. These trade-offs result from organisms having access to only a limited amount of resources in their life. Thus, species must decide (a decision made through successful strategies being evolutionarily selected) how to allocate these resources to needs such as growth, reproduction, and survival to get what researchers in Ng'Oma et. al refer to as “the most bang for their buck” (Ng'Oma, 2017).

To understand more about life history (particularly why some species can survive longer than others), researchers have familiarized themselves with the pace-of-life syndrome hypothesis. This concept explains that life history differences among species are interconnected to their behavior and physiology, and places species on a spectrum ranging from high metabolic rates to low metabolic rates (Polverino, 2018). The pace-of-living theory is based on the premise that there is a limit to the number of calories an organism can spend in its lifetime, and due to differences in the size of species (their surface area to mass ratio), some species burn through their calories at a faster rate than others. For instance, a mouse is much smaller than an elephant and has a lower surface area to mass ratio; it, therefore, has a higher metabolic rate and does not live as long as an elephant.

Certainly, understanding how life histories and the pace-of-living theory are intertwined is imperative to studying species' patterns of survival and reproduction. These theories serve as a useful tool when trying to understand the life history differences among amphibians. Amphibians are a group of cold-blooded animals who are characterized by their ability to metamorphose from a juvenile thriving in aquatic environments to an adult with lungs capable of surviving on land (“What are Amphibians?”) Amphibians can be further divided into 3 clades: Urodela, Anura, and Apoda; the differences between these clades are that urodeles possess tails as adults, anurans are tailless adults, and apoda are legless (Libretexts, 2019). While these are the marked physiological differences between these amphibian clades, there is also noteworthy variation in their reproductive traits. For instance, urodeles reproduce through internal fertilization and protect their offspring as they go through metamorphosis within their eggs (Libretexts, 2019). Alternatively, anurans participate in external fertilization, and provide

variable levels of parental care to their offspring who experience metamorphosis outside of the egg (Libretexts, 2019).

Intrigued by the variability in life history traits among species and specifically amphibians, as well as the pace-of-life syndrome hypothesis, this research seeks to better understand variation in reproductive success among different species of amphibians. Since the pace-of-life syndrome hypothesis suggests that species with a larger mass to surface area ratio have longer life spans, I hypothesize that larger amphibian species will have higher rates of fecundity, as they may have lower metabolism rates, allowing them to live longer and produce more offspring. This hypothesis also harps on the concept of resource allocation, as I postulate that larger species (higher body masses) may acquire and store more resources than smaller species, giving them an increased capacity to reproduce.

In relation to potential fecundity differences between urodeles and anurans, I suspect that anurans will generally produce more offspring than urodeles since external fertilization is a more efficient mode of reproduction (Boundless).

METHODS

To assess whether female amphibians with a higher body mass produce more young, the *Database for life history traits for European amphibians* was utilized. This database is comprised of life history data on 86 amphibian species in Europe, but only the species with reported data on offspring produced and body mass were included in the study, lowering the species richness to 36 species. This data was gathered from 304 scientific publications by searching sources including Web of Science, AmphibiaWeb 2012, and various books on herpetology.

A scaling analysis was used to demonstrate the relationship between body mass and the number of offspring produced. Then a linear regression analysis was completed in Excel to assess whether the relationship between these variables was significant for amphibians as a whole, the anuran clade, and the urodele clade.

RESULTS

Scaling analysis has indicated that there is a positive relationship between female amphibian body mass and the number of offspring produced (Fig. 1). Linear regression analysis indicates that this

relationship is significant (Table 1). Additionally, in regards to whether one clade of amphibians represented produced more offspring than another, this data demonstrates that urodeles with similar body masses to anurans tended to produce more offspring (Fig. 1). Linear regression analysis using only data from anuran species supported this finding, as the anuran clade was described to have a significantly positive correlation between body mass and fecundity, as displayed in Table 2. Alternatively, linear regression analysis using data on the urodele clade implicated a significant negative relationship between body mass and fecundity, with the number of offspring produced decreasing with body mass (Table 3).

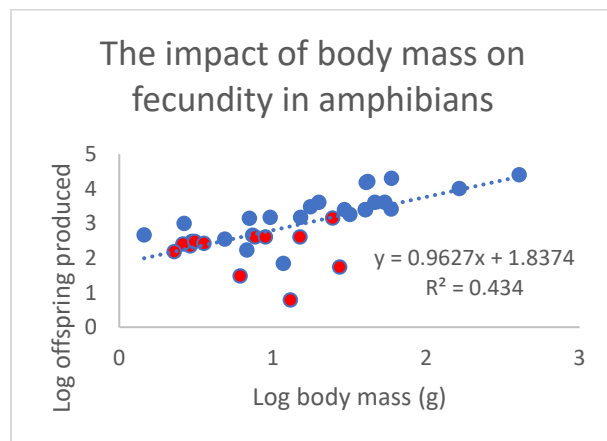


Figure 1. Scaling analysis demonstrates the positive correlation between body mass and produced offspring in female amphibians. The points colored red represent urodele species, while the points in blue represent anuran species.

Table 1. Completing a linear regression analysis on data from Fig.1 indicates the correlation coefficient (r) of body mass to produced offspring to be approximately 0.659. Additionally, the P-value for this relationship was found to be approximately 0.0000125 indicating how unlikely it is that these findings are a product of chance. As a P-value < 0.05 indicates significance, clearly, this relationship between body mass and offspring produced is statistically significant.

Correlation Coefficient	P-value
0.659	1.25 E-05

As indicated above, Table 1 illustrates that for amphibians as a whole, this study observed a significant, positive relationship between body mass and fecundity.

Table 2. Linear regression analysis using only data from anuran species indicates the correlation coefficient (r) of body mass to produced offspring to be approximately 0.778, representing a positive correlation. Additionally, the P-value for this relationship was found to be approximately 0.000000549, demonstrating that the positive correlation between body mass and the number of offspring produced in anuran species is statistically significant.

Correlation Coefficient	P-value
0.778	5.49 E-08

Data in Table 2 illustrates that for the anuran clade, a significant, positive relationship between body mass and fecundity, consistent to the findings for amphibians as a whole, has been described.

Table 3. Linear regression analysis using data collected from urodele species indicates that the correlation coefficient (r) of body mass to produced offspring to be approximately -0.154, representing a slight negative correlation. Additionally, the P-value for this relationship was found to be approximately 0.0000588, indicating that this relationship is significant.

Correlation Coefficient	P-value
-0.154	5.88 E-05

As illustrated in Table 3 this study observed a significant, negative relationship between body mass and fecundity for the urodele clade. This finding contrasts the significantly positive relationship between body mass and fecundity observed in the anuran clade, and in amphibians as a whole.

DISCUSSION

As, overall, a significant relationship between female body mass and the quantity of offspring produced was observed, this study demonstrates that larger amphibians produce more offspring than smaller amphibians, which supports my

original hypothesis. This finding is consistent with Darwin's "fecundity advantage" model suggesting that larger female animals produce a greater number of offspring (Shine, 1988). I suspect that this finding may be the result of resource allocation, as larger female species may be able to secure more resources than smaller females, permitting them to produce a greater number of offspring. This result may also be a product of the pace-of-living syndrome hypothesis proposing that larger species live longer than smaller species, thus expanding the time available to them for reproduction; with additional time to reproduce, it is possible that larger individuals will have the opportunity to produce a greater number of offspring than smaller individuals.

Additionally, this study demonstrated that anurans tend to produce more offspring than urodeles, as when comparing female species of the same body mass, the anuran species produced more offspring than the urodele species. This finding may be a reflection of the differing life histories of these clades, with anurans utilizing external fertilization and urodeles reproducing through internal fertilization. This study may promote the concept that external fertilization is a more effective method of producing young, as females can produce more young at a time than females engaging in internal fertilization.

Another plausible explanation as to why anurans were found to produce more offspring than urodeles is rooted in body shape differences. Anurans tend to have a wide, thick body shape, while urodeles have long, slender bodies. Due to this difference in morphology, anuran species are likely able to hold more eggs than urodele species, thus contributing to why they were found to produce more offspring. Additionally, urodele eggs tend to be larger in size than anuran eggs (Elinson, 2011); with more resources attributed to making large eggs, this may mean that urodeles produce a smaller quantity of eggs than anuran species.

In respect to how body mass influenced fecundity among anuran species, this study found a positive correlation between these variable consistent to that described for amphibian species as a whole. However, this study described a slight negative correlation between body mass and the number of offspring in urodele species. This finding is inconsistent with the positive correlation found in the anuran clade and for the amphibians as a whole. One potential explanation for this is that large urodele

species may face challenges which require using energy that would typically be devoted towards reproduction. For instance, perhaps large urodeles are targeted more by predators than small urodeles, meaning that these species would need to devote more energy to avoiding predators than the smaller species. Along that same line of thinking, it is possible that large urodele species may have shorter life spans than smaller species, meaning that they would have less time to reproduce than smaller species. While this explanation is certainly just a hypothesis, it may serve as a starting point in understanding this trend in the future.

This research has sparked interest in expanding in future directions. One area to be explored is whether larger female amphibians do indeed live longer than females with a smaller body mass. By assessing this data, one could be more confident in whether the pace-of-living syndrome hypothesis is the factor driving the positive correlation between body mass and offspring produced. Further, this research has indicated that anurans tend to produce more offspring than urodeles. To expand off of this finding, I would like to compare offspring mortality rates between urodeles and anurans. As urodeles reproduce through internal fertilization, I hypothesize that their offspring would have lower mortality rates than those of anurans since they are subject to an increased investment of energy and resources from their parents. Through the analysis of this data, it may be possible to draw conclusions on whether the fecundity difference described in this paper is a tradeoff for increased lifespan, with the different amphibian clades excelling in opposite areas. This research has laid the foundation for the investigation of these future questions and thus will continue to contribute to ecologists' effort to understand the various strategies that species use to promote their evolutionary fitness.

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